Title Page

- Title of Research:

  The relationship of microscopic material characteristics and physical behavior of quantum dots

- Key Researcher(s) involved in the Proposed Project:

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- Affiliation of Research(s):

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- Past AOARD or US government support:

  None

Abstract:

The research collected and analyzed the composition, structure and microstructure information at microscopic scales for the self-organized InAs/GaAs quantum dots through development of proper characterization techniques. The relationship between the microscopic materials characteristics and physical behavior, including quantum effect and optical properties was explored. The InAs/GaAs thin films were prepared using MBE process.

Introduction:

Quantum dot lasers have gained increasingly interest due to higher differential gain, lower threshold current density and higher T_0 as compared to quantum well lasers. Quantum dots are grown in highly mismatched systems by following the Stranski-Krastanow mode, instead of the Frank-Van der Merwe mode in growing quantum wells. Upon completing the growth of a two-dimensional wetting thin layer, the strain is partially released via the formation of coherent three-dimensional islands. Quantum dots will form when, first, it is energetically favorable for the film to relax by forming three-dimensional islands rather than by forming misfit dislocations and, second, the strain energy relieved by forming islands exceeds the additional surface energy resulting from islanding. Heteroepitaxy in the Stranski-Krastanow growth mode is one of the promising routes for fabricating QDs, because this process is not only self-assembling but also avoids the drawbacks of the lithographic techniques.

The processing parameters used in the fabrication techniques either MBE or MOCVD will affect the island structure in size, shape, density, chemical composition,

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lattice strain and surface diffusion and hence the associated optical properties. The correlation between the processing parameters and the structural characteristics becomes the key issue from the scientific viewpoint and should be well controlled. In the past decade, the main methods applied to investigate this issue include instrumentation techniques such as TEM, AFM, STM, XRD and SEM, and mathematical techniques such as modeling and simulation. The results acquired from the above techniques are verified each other. In addition, techniques such as PL, CL were then used to measure the opto-electronic properties for revealing the effects of processing on properties. The goal of this work was to focus on using several techniques in combination to explore the processing - structure - property relationship of the quantum dots infrared photodetector (QDIP) produced by MBE technique.

Approach:

The material used in the study was InAs/GaAs Single QDIP produced by MBE technique. Techniques involving TEM, SPM, SEM and PL were used for finding out the correlation between the structure characteristics of QDs and islands, properties and process parameters. The project was conducted by the following steps:

A. We compared the uniformity of the QDs before and after the GaAs layer was modified.
B. We compared the effects of different processing conditions like the growth temperature, the interruption time and the substrate orientation to the island size, shape, composition distribution and the lattice mismatch between the island structure and the surrounding matrix.
C. We analyzed the relationships between the structure features and process parameters with the corresponding opto-electronic properties, such as wavelength vs. composition, wavelength vs. growth rate, island shape vs. peak intensity, growth rate vs. QD density, growth rate vs. island size, and the effect of capping layer, and so on.
D. We used the analytical results for optimizing the process of QDIP.
E. We wrote this report.

Proposed collaboration:

We will cooperate with the Section in charge of QDIP fabrication in CSIST for providing the required samples and close discussions.

Summary

This research correlated the structure factors such as the size, shape and chemical composition and the corresponding opto-electronic properties. Consequently, acquirement of the structure factors accurately by analytical techniques including TEM, AFM and STM became better understood. In addition, it was proven to be an effective method for the manufacturer to modify the process parameters by using these results. By performing this project, not only the relationship of process-structure-property of the InAs/GaAs system became clearer, but also the environment of both fabrication and analysis of quantum dot was completely constructed. The QDIP and other derivative devices will be expectable in the future.